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Original Article

Mitigation of Urban Air Pollution Through Aeroponic Planting Methods: A Sustainable Approach

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Abstract - *Air pollution is a major problem in urban areas that has a detrimental effect on people's health and wellbeing. This pilot study examined the consequences of air pollution in Chennai's Royapettah neighbourhood. The World Health Organization (WHO) issues the critical alert known as the "AQI" (Index of Air Quality), indicating that the air quality in the Royapettah zone of central Chennai is between 150 and 170 AQI, with a permitted limit of 50 AQI. The study suggests using an algae tank and the aeroponic planting technique as a sustainable way to reduce air pollution and improve the health of city dwellers. In addition to reviewing relevant literature and case studies, this study looks into the viability of using an algal tank and aeroponics planting to reduce air pollution and enhance both indoor and outdoor air quality. To measure the amount of air pollution, a balcony with an algae tank and aeroponics system planted for one month was compared to one without plants for one month (April 2024) using Arduino smart sensors that sense components like gas, humidity, temperature, oxygen, particle matter, and dust. According to the results, the aeroponic tower planting method was found to be an efficient way to reduce air contaminants such as carbon dioxide, Volatile Organic Compounds (VOCs), and particulates on balconies with green features like algae tanks and aeroponics systems. Environmental pollutants have significantly decreased as a result of algae tanks' ability to absorb pollutants such as carbon dioxide and carbon monoxide. Evidently, aeroponic plants and algae are best absorbed in their natural surroundings free of contaminants, and they also enhance the quality of the indoor environment and promote vital health. All things considered, the results emphasize the relevance of aeroponic gardening techniques as an organic means of reducing air pollution and fostering healthier urban settings.*

Keywords - *Indoor air quality, Algae, Native species, Aeroponics method, Air pollution and Health effects, Air quality monitoring and management.*

1. Introduction

In six main cities, the number of Urban Agglomerations (UAs) has increased noticeably: Bangalore, Hyderabad, Delhi, Mumbai, Kolkata, and Hyderabad. Air pollution has long been an issue in Tamilnadu, India, due to the region's dense metropolitan population. The region's quick industrialization, urbanization, and economic growth, along with the rise in energy demand, are the key causes of this [1, 2]. Chennai and other major Tamil Nadu cities Owing to variations in demographic features, including altered land use patterns, anticipated growth of population, change in climate, and urban expansion, the air pollution level is observed to be five times higher than the prescribed levels of World Health Organization (permissible level is 50 AQI), and it has the highest UA in India [3]. According to the World Health Organization, the Air Quality Index in Royapettah zone, Chennai, is 179, measured by the Tamil Nadu Pollution Control Board, which is a sensitive warning statement. The pollutants under observation include CO, CO_2, PM- 10, PM- 2.5, SO_2, NO_2, NH_3, formaldehyde, TVOCS, and benzene. The Tamil Nadu Pollution Control Board monitors the air quality of Chennai through five stations (Table 1) [1, 7-12].

There are numerous sources of indoor air pollution. Typical forms comprise particulate matter released during combustion processes such as heating and cooking, Volatile Organic Compounds (VOCs) from paints, building supplies, and cleaning agents, and biological pollutants from mold, pollen, and pet dander. Tobacco smoke, which emits toxic compounds, and home items like insecticides and air fresheners are additional sources. These pollutants can build up in areas with inadequate ventilation, which can affect indoor air quality and perhaps lead to health problems.

Fine particulate matter found in indoor pollutants like PM2.5 and PM10 can enter the circulation and pierce deeply into the lungs, resulting in respiratory and cardiovascular problems. Nitrogen dioxide and sulphur dioxide can exasperate respiratory disorders and make asthma attacks worse.

Table 1. Air quality index prescribed by National Ambient Air Quality Standards, Environmental Protection Agency

Pollutants	Allowable Annual Value (μg/m^3)	Maximum allowable Daily Value - μg/m^3
PM 2.5	35	9–12
Nitrogen	40	80
Carbon dioxide	15	37.5
Carbon monoxide	35	75
Formaldehyde	5	100–120
Benzene	5	100
Sulphur	20	80
Ammonia	100	400
PM 10	15	45
Volatile organic compounds - $C_2H_2C_{l2}$	5 - 7	200

Gases that can impact cognitive function are carbon dioxide (CO2) and carbon monoxide (CO), which can both obstruct the body's ability to provide oxygen. Two volatile organic compounds that have been connected to respiratory issues and cancer are formaldehyde and benzene. Ammonia (NH3) has the potential to irritate the respiratory system, skin, and eyes. These pollutants' combined effects have the potential to cause serious health issues, such as respiratory infections, chronic illnesses, and the aggravation of pre-existing problems.

Air pollutants that living organisms breathe constitute a greater risk to human health and the environment, including sulphur dioxide, particulate matter, nitrogen oxides, ozone, and volatile organic compounds [4]. Moreover, when inhaled through the respiratory system, it can cause cancer, diseases of the reproductive and central neurological systems, respiratory and cardiovascular conditions, and other grave health problems [5]. While certain creatures are found both indoors and outside, others penetrate indoor spaces from the outside, affecting both human health and indoor air quality [6]. The National Ambient Air Quality Standard specifies the maximum allowable level of pollution and its average concentration (Table 2).

Table 2. The National Standard for Ambient Air Quality for India lists air contaminants and the acceptable levels for each.

Environmental Quality Index (AQI)	Dividends
0-50	Good
51-100	Adequate
101-200	Poor
201-300	Modest
301-400	Incredibly Minimal
401-500	Extreme

According to numerous studies, due to air pollution indoors, children's health is at great risk with respect to chronic obstructive pulmonary disease and acute respiratory infections, particularly if they are younger than five years old and reside in developed countries. As per the 2020 World Health Report, the worldwide disease burden is 4.1% due to interior pollution, which is ten times greater than outside pollution [13].

Conventional approaches to mitigating air pollution, such as industrial control and urban planning, have had varied degrees of effectiveness, but they frequently fail to address the issue while it is becoming worse very quickly. As a result, creative, sustainable methods of reducing air pollution that have the potential to be more scalable and successful are becoming more and more popular. Aeroponics is one such cutting-edge technique that grows plants without the need for soil in an air or mist environment. Aeroponics' potential benefits for improving air quality have been largely disregarded in studies that have already been done, even though they have mostly been studied in relation to agricultural efficiency and food production. By analyzing the feasibility and effectiveness of using aeroponics as a tool for mitigating air pollution, this study aims to address this research gap.

This study suggests a fresh, environmentally friendly method for reducing air pollution by utilizing aeroponics' natural advantages. In contrast to traditional techniques, aeroponics offers a flexible way to improve the quality of air in urban areas, including rooftops and vertical gardens. Additionally, this study attempts to contrast the effectiveness of aeroponic systems and conventional green infrastructure techniques in reducing air pollution. This study will offer empirical support for the feasibility of aeroponics as a long-term urban air quality management strategy through the conduct of field research and controlled tests.

2. Literature Study

2.1. The Consequences of Indoor Air Pollution on Inhabitants' Health

Particulate matter, radon, nitrogen compounds, volatile and semi-volatile organic compounds, SO2, O3, CO, and microbes are examples of indoor air pollutants [14]. Indoor particulate matter 2.5 and 10 have been tied to premature death and a number of heart and respiratory illnesses. Volatile organic compounds, or VOCs, are present in building materials, surfaces, and furniture. They have been linked to inflammation of the ENT tract, nausea, cancer, and harm to the kidney, liver, and central nervous system. Appliances that heat and cook produce NO2, which aggravates asthma attacks and breathing problems.

In addition to causing lung damage and respiratory depression, disinfectants and air purifiers damage DNA. Fireplaces and cooking stoves emit SO2, which aggravates breathing and raises the possibility of cardiovascular, pulmonary, and chronic obstructive pulmonary diseases. Chest pain, exhaustion, and reduced cognitive function can result from the aerosols and carbon compounds released by smoking tobacco, using fireplaces, generators, and other gasoline-powered appliances. Radon is present in tap water, building supplies, and soil gas, and it causes lung cancer. Carpets, fabrics, and padded furniture are examples of building materials that irritate the eyes, nose, and throat, in addition to damaging central nervous systems and the kidneys, which raises the possibility of cancer. Relative humidity, cockroaches, houses prone to dust, pet animals, flowering plants, and insects are examples of biological allergens that can lead to respiratory allergies, sensitization, and wheezing [15, 16]. A number of studies have been conducted to address the issue of Indoor Air Quality (IAQ). Currently, efforts are being made to investigate the usage of native plant species and algae that are tolerant of air pollution as potential remedies for the problem of IAQ [17].

2.2. Air Pollution and Particle Matter are Absorbed by Plants

Plant systems, growth and utility are all impacted by air pollution, and these changes can have an adverse impact on a plant's morphology, biochemistry and physiology. Plant species that are both sensitive and tolerant to pollution must be identified and categorized as the use of plants to reduce air pollution spreads, especially in the form of vertical green wall systems [18, 19]. Phytoremediation strategies for pollution neutralization have been identified through a journal analysis. These strategies include Bioremediation using algae, fungi, and bacteria, phytoremediation, vermiremediation, and zooremediation are the five categories of remediation techniques [20].

According to Kim et al. (2020), plants absorb and break down airborne contaminants as part of the atmospheric phytoremediation process. Plants above ground primarily absorb pollutants through the stomata on their leaves. (Kulshreshtha et al.) [21, 22]. Air contaminants can be absorbed by plant surfaces, which lowers their concentration in crowded locations [23]. The best plant species for eliminating air pollution have been found to be English ivy Hemigraphis Alternata, asparagus fern and honeysuckle [24]. Numerous plant species, including Ficus benjamina, Chlorophytum comosum, and Dracaena, or their parts, have been shown in an increasing amount of studies to either continuously reduce indoor microenvironment air pollution concentrations or improve human health [25].

A 1989 study by the American Landscape Association (ALCA) and the National Aeronautics and Space Administration (NASA) found that house plants are a great way to filter interior air since they absorb airborne pollutants and hazardous gasses [26]. The intrinsic ability of plants to withstand air pollution is shown by the APTI (Air Pollution Tolerance Index), a useful measure for categorizing plants according to their sensitivity or tolerance to air pollutants [27]. The pH of plant leaves, RWC (Relative Water Content), ascorbic acid, and total value of chlorophyll are measured to determine it. APTI values of ≤ 11, 12–16, and ≥ 17 are associated with tree species that are categorized as sensitive, moderate, and tolerant to air pollution [28]. High indices of tolerance to air pollution are possessed by Thespesia populnea, Terminalia catappa, Magdalena champaca, Psidium guajava, Bougainvillaea spectabilis, Mangifera indica, and Albeza Lebbeck. Some species that are particularly vulnerable to air pollution include Tecoma stanus, Bauhinia variegata, Tabernaemontana divaricata, and Muntingia calabura. These plants have low tolerance indices. Enhancing vegetation and lowering air pollution can be achieved by planting species that have a high air pollution tolerance index.

Additionally, plant-derived algae may help improve the quality of air in towns and cities. Because photosynthesis is carried out throughout the body, the body's capacity to fix CO2 is ten times greater than that of a huge tree. In order to develop, algae must consume pollutants like CO2, CO, NO2, and VOCs. As a result, oxygen is spontaneously released into the atmosphere by algae [29]. Algae release 1.33 grams of oxygen and absorb 1.83 grams of carbon dioxide per gram, and they also store 0.5 grams of carbon [30]. Using algae like spirulina to produce oxygen, a filthy air system can reduce carbon dioxide, nitrogen oxide, and Sulphur oxide [31]. Using Wi-Fi, Bluetooth, Zig-Bee, GPRS, and GPS as communication methods, wireless sensor networks and the Internet of Things can be used to track air quality data [32]. To measure the amount of Carbon monoxide, Nitrogen dioxide, Sulphur dioxide, dust, particle matter, and other air pollutants, a variety of sensors, including gas, humidity, temperature, oxygen, particulate, and dust sensors, are positioned in various locations [33].

2.3. Current Improvements and Monitoring of the AQ

To understand the extent to which particles and gas concentrations can contribute to air pollution, air pollutant levels must be monitored. Mathematical theory can be utilized to detect and forecast the behaviour of air pollutants using air pollution modeling, which makes use of the monitored parameter.

The environment can also be protected by using this analyzed data to avoid and regulate air pollution factors [34]. Because pollution concentrations in the air have an impact on air movement, one can research air pollution by analyzing meteorological data for a certain area. The source of pollutants and inversions, as well as the days when there would be a high concentration of pollutants in the air, may all be predicted using meteorological data [35].

Modern technology for monitoring and modeling makes it possible to create and refine universal multi-pollution indicators for tracking the effects of air pollution on wellbeing and the economy, as well as to support the implementation of programs to track and manage ambient air quality improvements [36]. A multitude of Internet of Things (IoT) sensors monitor temperature, humidity, light intensity, and total dissolved solids in the indoor environment [37]. The availability of data from IoT technologies has resulted in the creation of a larger database that can be used to identify AQI. With existing data, air pollutants, namely particulate matter, NO_x, SO_2, CO, and O_3 can be noticed for future projections [38].

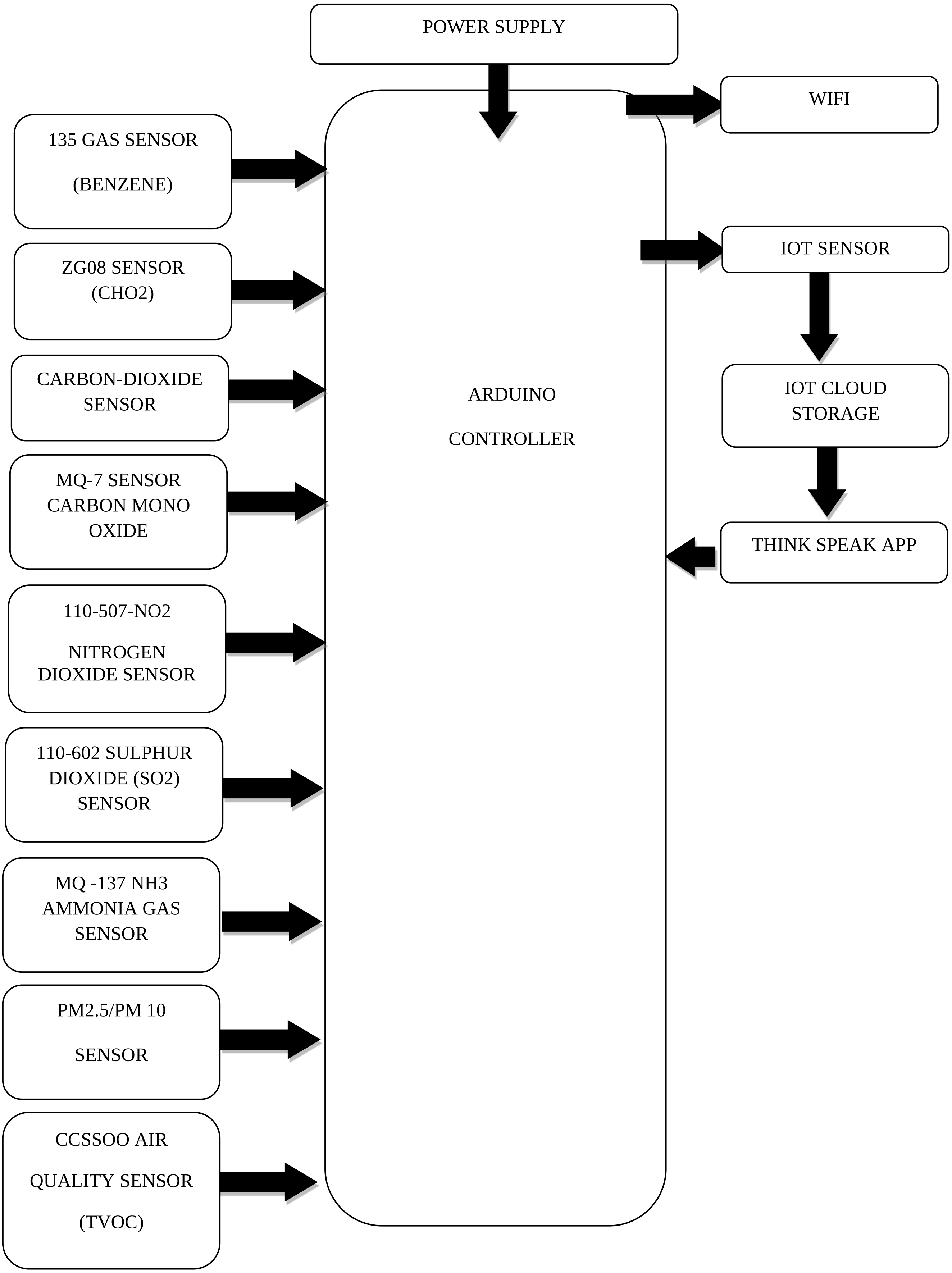

Fig. 1 The block structure of an Internet of Things-based air quality monitoring system

Thus, the study aims to determine the types of indoor air pollution that exist in indoor environments. Effective strategies for managing and enhancing IAQ for a sustainable built environment are also being discovered in the case region of Royapettah, Chennai, Tamil Nadu, India. These strategies include the use of algae tanks to introduce native species and aeroponics plant growing technologies. The Arduino Sensor Kit, an inventive method of monitoring air quality, keeps tabs on the primary indoor air pollutants, as illustrated in Figure 1.

3. Materials and Methods

3.1. Pilot Study Area

The Urban area considered for the pilot study is Royapettah, situated in the southern part of Tamil Nadu, Chennai, with a Density in population of 39269 per square kilometre [39]. Population density per square kilometre according to the National Transit Oriented Development (TOD) congested area classification is shown in Table 3.

Table 3. The density of dense regions per square kilometre according to the National categorization for Transit-oriented development

Classification	Population/Sq.km. Density
Extremely minimal	Less than 100
Minimal	101 to 270
Moderate	271 to 600
Superior	601 to 1000
Highly elevated	Greater than thousand

A three-story separate dwelling residence has been located, and the study has focused on the second floor of the building. As seen in Figure 2**,** planting ideas have been selected close to the windows measuring 1.30 m x 1.20 m of three bedrooms facing the main road oriented towards the south, as indicated in Figure 3**,** which is subjected to construction activities, dust particles, and traffic all day long.

Fig. 2 The resident case study at Royapettah from the roadside

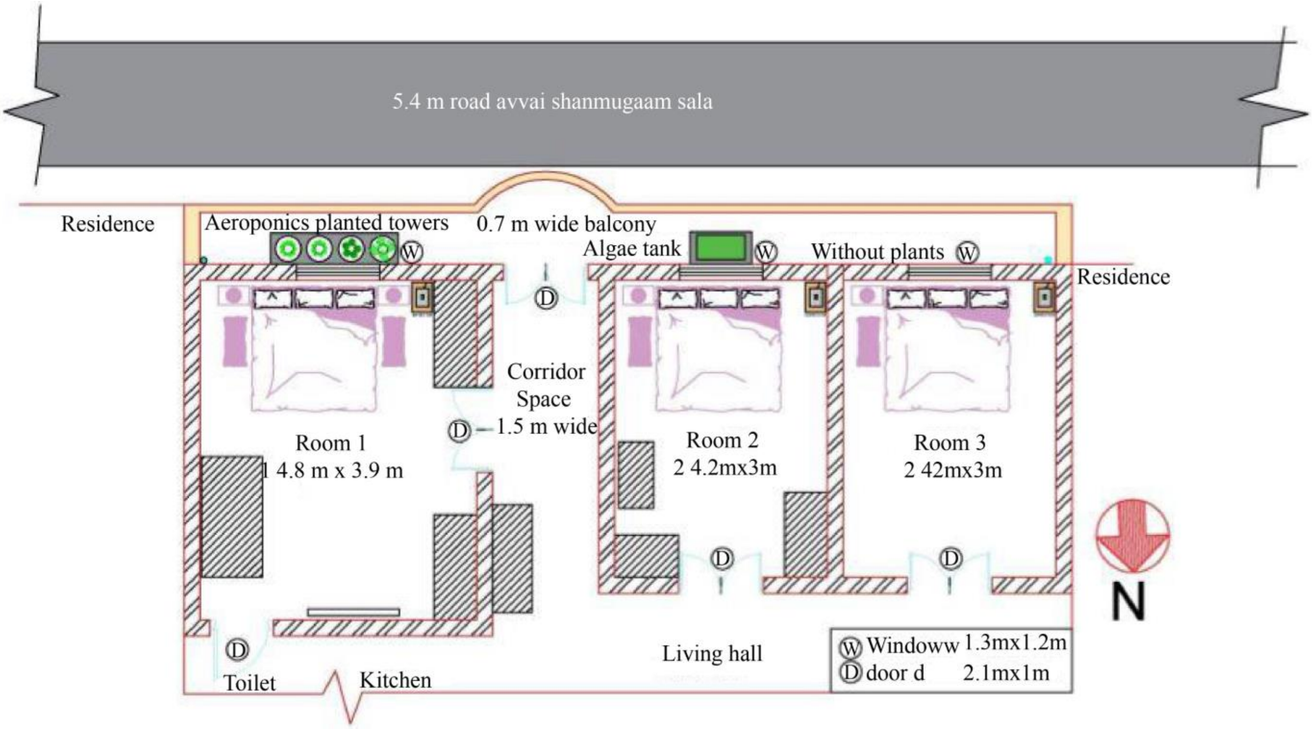

Fig. 3 Pilot research on identified residents at Royapettah

3.2. Introduction of Natural Plant Types and Algae

Three areas of emphasis for the research design are as follows:

- An aeroponic tower with plants placed close to Bedroom A's window, together with an Audrino controller, to track the quantity of Nine pollutants absorbed by the plant species over the course period of one month. A list of suggested plant species is provided in Table 4.
- An Audrino controller-equipped algae tank is positioned next to the window of Bedroom B to monitor the amount of nine contaminants that the spirulina algae absorb over a month.
- An Audrino controller to monitor nine pollutant concentrations for a month (April 2024) is installed in bedroom C, which is not planted.

Table 4. Enumeration of suggested plants for eliminating indoor air pollution

Plants Species (Common Name)	Scientific Name	Picture	Benefits
Dumb canes	Dieffenbachia		Aids in the removal of airborne pollutants like xylene and Tvocs.
Spider Plant	Chlorophytum comosum		The air purifying plant combats formaldehyde, xylene, carbon monoxide, and carbon dioxide.
Boston Fern	Nephrolepis Exaltata		Boston ferns are natural air purifiers that absorb air pollutants such as Tvocs, formaldehyde, xylene and toluene and release oxygen.
Warneck Dracaena	Dracaena deremensis		Eliminating PM2.5 and 10 formaldehyde, benzene, trichloroethylene, and xylene particles from the atmosphere.
Philodendron	Philodendron		Removing formaldehyde
Tomato Plant	Solanum lycopersicum		Eliminating 71 percent of the phosphate and 58 percent of the nitrate.
Mint Plant	Mentha		Air contaminants include xylene, carbon monoxide, formaldehyde, benzene, and particle matter.
Kale	Brassica oleracea var. sabellica		Formaldehyde, xylene, carbon monoxide, and benzene
Broccoli	Brassica oleracea var. italica		Xylene, benzene, formaldehyde, carbon monoxide, and carbon dioxide
Spinach	Spinacia oleracea		The air purifying plant combats formaldehyde, xylene, carbon monoxide, and PM 2.5 and 10.
Algae-Spirulina	Arthrospira platensis		In contaminated air, sulphur oxide, nitrogen oxide, and carbon dioxide can all be reduced by spirulina while simultaneously producing oxygen.

3.2.1. Aeroponic Plant Tower Location with Respect to Bedroom A

Aeroponics is the practice of growing plants without soil in nutrient-rich mist environments. In contrast to hydroponic systems, aeroponic systems allow plant roots to take up nutrients directly from the aerosol without having to come into contact with a liquid medium [40].

Beside the bedroom is the aeroponic chamber. The chamber is 63.48 x 30.48 x 152.4 cm, has a window measuring 1.3 x 1.2 m, weighs 2.27 kg, and is equipped with a submersible water pump that is linked to a 20-liter nutrient storage capacity at its base. Each tower has twenty-four planting net pots.

Sprinkle the nutrient solution on the roots of the plant intermittently using a misting device that has been set up inside the area. "The efficient use of plants to remove, detoxify, or immobilize environmental contaminants" is how the UNEP (2019) defines phytoremediation. Cleaning contaminated material with phytoremediation is advantageous and safe for the environment. The procedure comprises the absorption of pollutants through the roots, their accumulation inside the body's tissues, and their degradation and transformation into less dangerous forms. [41-43]. Set the timer to spray nutrients for a few minutes every hour, depending on the needs of the plant. Nowadays, any plant may be grown using aeroponics. Chennai, a city with a tropical environment that is warm and humid, is where the aeroponics tower is located, as shown in Figures 4(a) and 4(b) [43]. This approach works best with edible plants like tomato, mint, kale, broccoli, and spinach and non-edible indoor species like Dieffenbachia, spider plant, dracaena, Boston fern, and philodendron. For the study, perennial green plants that are good at absorbing pollutants to improve indoor air quality—like kale, broccoli, spinach, tomato, and mint—have been taken into consideration. The experiment was designed using in situ attenuated total reflection and photosynthesis in the leaves of Brassica oleracea. A FTIR (Fourier transform infrared) spectroscopy test was conducted to determine thallium pigmentation in kale leaves. The analysis revealed no significant variation in the absorption of thallium pigmentation. Significant peaks may be attributed to the absorption of macromolecules at 3,380 cm (-1); significant rises at 2,916 and 2,850 cm (-1) may be attributed to the concentration of carbohydrates or aliphatic compounds [44]. Broccoli sprouts were shown in clinical studies to enhance air pollution detoxification. When broccoli sprouts are chewed or consumed as a beverage, the compound glutarothenin is transformed into sulforaphane. In order to strengthen the body's capacity to get rid of different kinds of pollutants, it works by increasing the production of enzymes [45]. During the finish of the growth season, the exposure of O_3, the interchange of gases, and a few more parameters were evaluated. Floating values of Fluorescence were reduced at elevated concentrations of O_3, indicating a change in the effectiveness of the Photosystem's energy conversion [46]. Tomatoes help with Particulate matter, are highly lethal to humans and can induce lung and cardiac ailments. The primary cause of environmental pollution is automobiles. Hence, people should stop living close to roadways and conducting human activity there [47]. An efficient weapon against the rising levels of indoor pollution is a common houseplant called mint. NASA has found that plants can eliminate up to 87% of the volatile organic compounds in the atmosphere in a single day. Benzene, Toluene, Xylene, formaldehyde, and trichloroethylene are some of these toxins. Breathing in tiny spaces is made simpler by mint [48].

Anthurium, pathos, and spider plants are less efficient carbon dioxide absorbers than Dieffenbachia in houseplants. The study examined thirty plant species that are members of the Agavaceae, Araceae, and Liliaceae families and their capacity to remove formaldehyde from the atmosphere. A glass box of 1.00 m x 1.00 m x 0.80 m was used to hold each plant for seven days. Initially, 15 mg m-3 of formaldehyde was placed within the glass box. CV Aglaonema Commutatum. The plants that demonstrated the strongest resilience to the detrimental effects of formaldehyde pollution were white hogweed and Spathiphyllum-floribundum. The other species that showed the strongest resilience were A. commutatum. Sansevieria trifasciata. Hahnii, D. sanderiana, and D. deremensis cv. Compacta. The species with the second highest resilience were Silver Queen and Alocasia macrorrhiza, which contained Dieffenbachia amoena CV. A. CV Camilla Commutatum [49]. As an antioxidant, spider plants effectively remove harsh chemicals found in cleaning products and furniture, such as ammonia, benzene, formaldehyde, and xylene. 90% of the poisons must be removed in two days or less. Spider plants are one well-known type of plant that cleans the air. Having a plant like this is an excellent idea, especially in the kitchen and bathroom, where common household products like putty, glue, and fillers contain formaldehyde, a carcinogen [50]. Warneck dracaena is a plant that thrives well in room temperature conditions with minimal light. Wax, benzene, formaldehyde, and trichloroethylene can also be eliminated with its help. Research indicates that dracaena plants are some of the greatest air purifiers available. The factory removes formaldehyde, benzene, trichloroethylene, and carbon dioxide, all of which are linked to a number of health problems. Furthermore, dracaena plants tend to increase room humidity, which aids in the management of respiratory conditions [51]. The Boston fern restores the natural humidity in the air and serves as a natural air filter.

Due to its moisturizing properties, the plant has been shown to be helpful for people with dry skin or sore noses and throats. Nephrolepis Exaltata, or Boston, is the opinion of Dr. Bill Wolverton, one of NASA's leading authorities in air quality research. Ferns are among the best plants for removing common air pollutants like toluene and xylene [52]. Plants with philodendron leaves clean the air by removing formaldehyde, which is often found in furniture and building supplies. Natural sources of formaldehyde are present; prolonged inhalation of the chemical can be hazardous.

Fig. 4(a) Positioning of an aeroponic plant tower

Fig. 4(b) Positioning of an aeroponic plant tower

3.2.2. Spirulina Tank Arrangement Next to Bedroom B

Spirulina, an algae. Even though roots and tubers are less common in this system, they can nevertheless be grown with the most sophisticated infrastructure. Spirulina can create oxygen in addition to reducing the amounts of carbon dioxide, sulphur dioxide, and nitrogen dioxide in the atmosphere. A Fibreglass tub of 2 feet by 2 feet in size, which holds 226 litres of water cultivation liquid-rich, beneficial bacteria along with 1.38 Gms of dried algae and an air feeder with the motor facility is part of the setup.

In order to produce oxygen, photosynthesis needs CO2, sunlight, and fluorescent lamps above the tank, as seen in Figures 5(a) and 5(b) Photosynthesis takes place during the day. Algae also take up nutrients from the interior air during photosynthesis, including nitrogen dioxide (NO2) and Sulphur dioxide (SO2). The two primary dangerous gases present in the tainted air are SO2 and NO2. Numerous methods can be employed to investigate the concentrations of SO2 and NO2. During photosynthesis, one of the most important nutrients for spirulina is the NO2 and SO2 gases present in the atmosphere. It is possible to calculate the amounts of NO2 and SO2 in the contaminated air by measuring the amount of these gases dissolved in spirulina (algae).

Fig. 5(a) Spirulina in an algae tank

3.2.3. Setting Up an Audrino Controller in an Open Space Near Bedroom C

The Audrino controller was placed in bedroom C, which is not planted, next to a 1.3 x 1.2 m window to monitor the concentration of nine pollutants for a month, as shown in Figures 6 and 7.

Fig. 5(b) Algae tank - Spirulina

Fig. 6 An unplanted area with an Arduino controller set up

3.3. Sensor Integration to Track Performance of Air Pollutants

Arduino controller sensor box will be used to track the local pollutants in the air starting in April 2024. Benzene, formaldehyde, SO2, NO2, NH3, PM- 10, PM- 2.5 are the most frequently occurring air contaminants.

4. Results and Discussions

4.1 Aeroponic Tower Planting's Absorption of Air Pollutants

Aeroponics farming seems like a feasible solution given the high levels of ammonia, TVOC, formaldehyde, benzene, CO_2, CO, NO_2, and SO_2, as well as PM- 2.5 and PM- 10. The south-facing bedroom is exposed to high levels of vehicular pollution, which an exceeding 179 AQI worsens.

Fig. 7 Sensor device of Arduino

Plant growth and the balcony's air quality both significantly improved with the use of the aeroponic tower planting technique. Aeroponic towers, with their vertical plant arrangement, enabled the growth of a wide variety of flora while optimizing the use of available space. The plants demonstrated their adaptability to the aeroponic environment with their robust growth and rich foliage. Additionally, the roots of the plants were treated with a nutrient-rich mist, which enhanced their general health and made it possible for nutrients to enter them more successfully.

Aeroponic plants, including warneck, philodendron, spider, dieffenbachia, and Boston fern, are excellent absorbers of air pollutants, including nitrogen oxides, particulate matter, and volatile organic compounds. Dieffenbachias are known to absorb carbon dioxide and formaldehyde, native spider plants are good at removing both formaldehyde and carbon monoxide, Dracaena are significant in eliminating ammonia (NH3), and Sword ferns are notable for their capacity to rid off formaldehyde [49-52].

Utilizing the natural ability of plants like Tomato, Mint, Spinach, Kale, and Broccoli to absorb a range of air pollutants, aeroponic gardening offers a comprehensive approach to air hygiene. Though every plant species has a different profile of pollutant absorption, all plant species help remove particulate matter, nitrogen oxides, and volatile organic compounds from the exterior and interior environment. Broccoli successfully eliminates formaldehyde, tomatoes effectively remove benzene, mint is wonderful at removing both formaldehyde and benzene, and kale is well known for its capacity to absorb Sulphur dioxide. Palak also aids in the removal of volatile organic compounds [44-48]. Aeroponic systems enable better root oxygenation and nutrient delivery, which improves plant absorption of pollutants.

Due to the effective filtering capabilities of plant roots suspended in a nutrient-rich mist, aeroponic planting can absorb air contaminants. This natural ability to absorb and break down air pollutants is evident upto 20% in volatile organic compounds, nitrogen oxides – 4%, Carbon components – 28% and particulate substances – 27%. This novel method takes advantage of plants' ability to do so, as demonstrated in Table 5**.** With its growth-friendly environment that fosters quick plant development, aeroponics enhances both the quality of the air and the plant's capacity to absorb pollutants. With its potential to significantly lower indoor and outdoor air pollution, this technology is a sustainable and environmentally responsible approach to reducing the harmful effects of air pollution on human health and the environment. In the aeroponic tower planting technique, air pollutants such as volatile organic compounds, carbon dioxide, and particulate substances were successfully reduced (Figure 8). The plants vigorously absorbed these pollutants through their leaves and roots, purifying the air on the balcony. Furthermore, the presence of plants improved the space's comfort level by contributing to the cooling impact through transpiration.

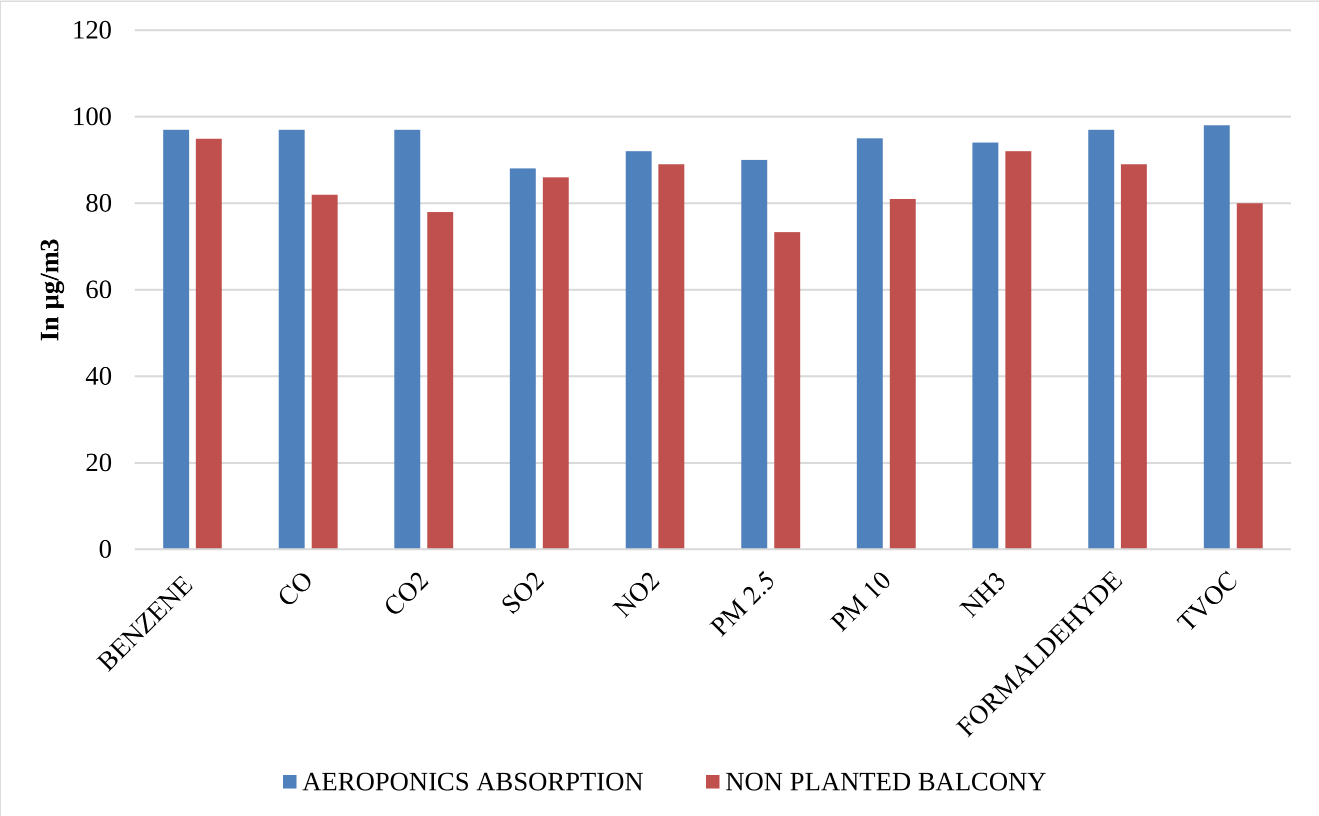

Fig. 8 Aeroponic tower planting absorbs air pollutants

Table 5. Average values - Absorption of air pollutants by aeroponic tower planting.

Gases and Pollutants	Benzene - (C6H6)	Carbon - monoxide (CO)	Carbon - dioxide (CO2)	Sulphur - dioxide (SO2)	Nitrogen - dioxide (NO2)	Particulate Matter - PM 2.5	Particulate Matter - PM 10	Ammonia - (NH3)	Formaldehyde- (CH20)	Volatile Compounds- (TVOC)
Aeroponics absorption	97	97	97	88	92	90	95	94	97	98
Non-planted balcony	95	82	78	86	89	73	81	92	89	80

4.2. Algae Tank Planted Balconies Absorb Air Pollutants

Spirulina-filled algae tanks function as potent biofilters, removing nitrogen oxides-NOx, Sulphur dioxide, particulate matter, and 24% carbon components from the air, as shown in Table 6. Spirulina absorbs carbon dioxide (CO2), releases oxygen through photosynthesis, and breaks down sulphur dioxide and nitrogen oxides. In addition to being a sustainable and eco-friendly method of air cleaning, algae tanks generate valuable biomass that is high in protein and nutrients.

Utilizing a water tank for the growing of algae, the algae tank planted balcony provided a novel method for improving air quality and enhancing aesthetics. Algae have a well-known ability to both consume and generate oxygen through photosynthesis, which helps to filter the air (Figure 9). The absorption of pollutants is less in aeroponic tower planting than in aeroponics planted balconies, but algae tanks may need more upkeep and supervision to keep the water clean and prevent algae overgrowth.

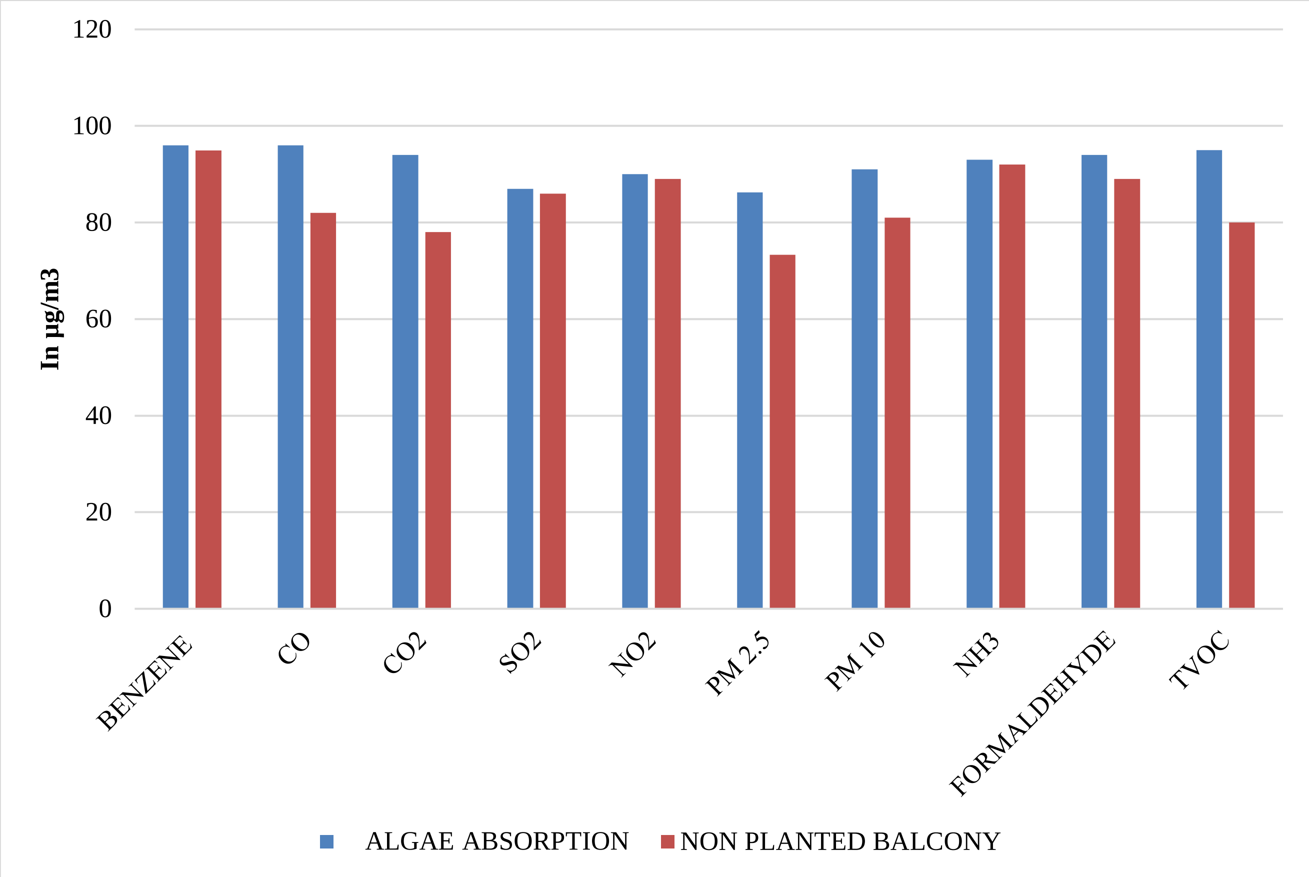

Fig. 9 Absorption of air pollutants by algae tank planted balcony

Table 6. Average values - absorption of air pollutants by algae tank planted balcony.

Gases and Pollutants	Benzene-(C6H6)	Carbon - monoxide (CO)	Carbon - dioxide (CO2)	Sulphur-dioxide (SO2)	Nitrogen - dioxide (NO2)	Particulate Matter -PM 2.5	Particulate Matter - PM 10	Ammonia-(NH3)	Formaldehyde-(CH20)	Volatile Compounds-(TVOC)
Algae tank absorption	96	96	94	87	90	86	91	93	94	95
Non-planted balcony	95	82	78	86	89	73	81	92	89	80

As demonstrated in Table 7, indoor aeroponics systems, in conjunction with edible plants and algae tanks, show promise in terms of air pollution absorption. Thanks to their mutualistic relationship, plants and algae are able to efficiently filter out commonly prevailing air pollutants. This offers a sustainable way to grow food in addition to enhancing the quality of the air indoors. Aeroponics and edible plants work together to improve air purification effectiveness and provide a nutritious crop, which makes it a practical indoor air pollution mitigation solution that also encourages self-sufficiency in food production. When comparing aeroponics to algae culture, aeroponics produced better results, making it the best option for sustainable farming methods.

Table 7. Average values - Air pollution absorbed by balcony plants with algae and aeroponic tower plants

Gases and Pollutants	Benzene (C6H6)	Carbon-monoxide	Carbon-dioxide	Sulphur-dioxide	Nitrogen dioxide	PM -2.5	PM -10	Ammonia	Formaldehyde	TVOC
Non-planted balcony	95	82	78	86	89	73	81	92	89	80
Algae tank absorption	96	96	94	87	90	86	91	93	94	95
Aeroponics absorption	97	97	97	88	92	90	95	94	97	98

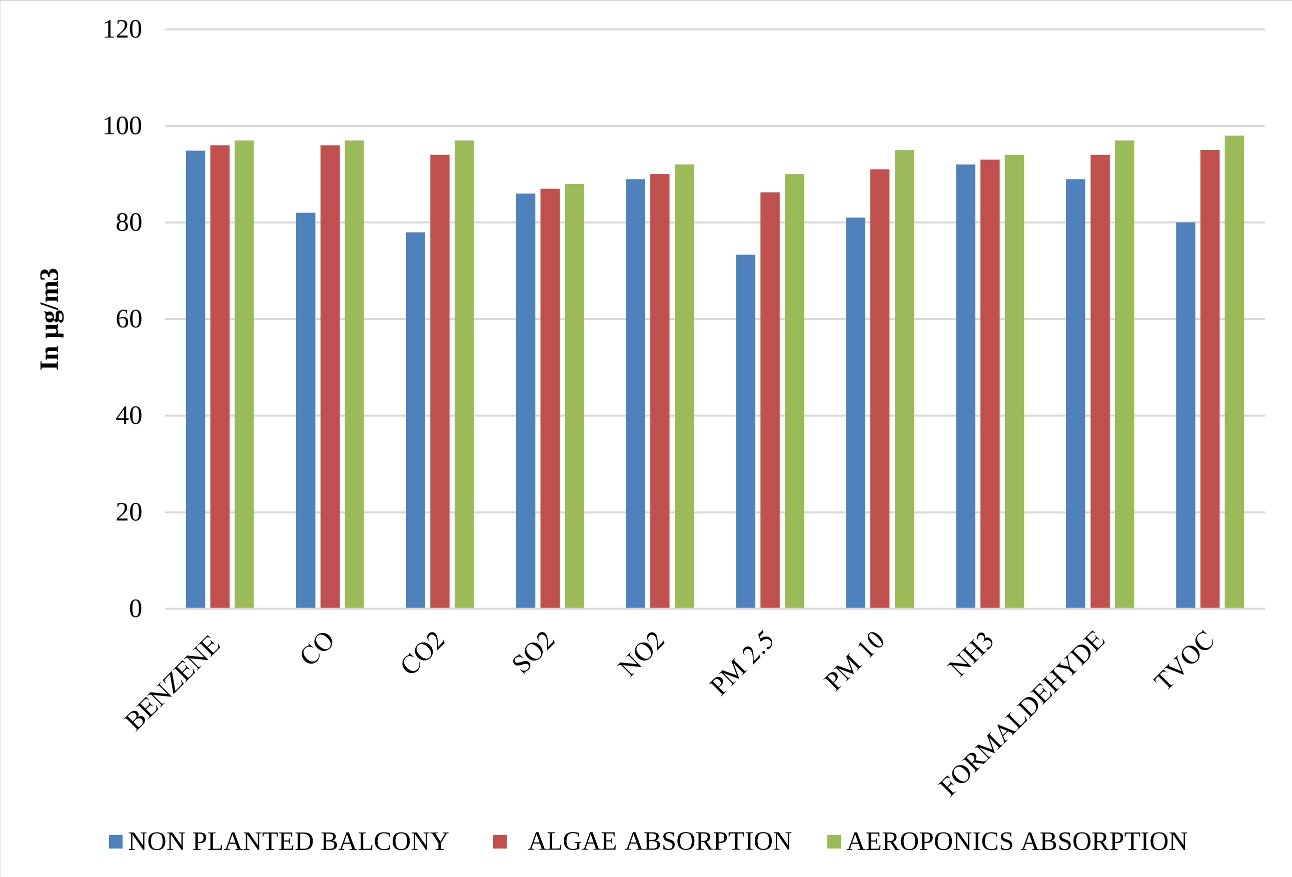

Fig. 10 Absorption of air pollutants by algae tank and aeroponics- planted balcony

5. Recommendations

In conclusion, to sum up, using algae tanks with aeroponic towers to reduce indoor air pollution is a novel and sustainable approach. Utilizing the natural powers of plants and algae, this method provides a comprehensive fix that not only purges the air but also builds environmental resilience. The algal tanks help produce oxygen and sequester carbon, which together lessen the negative effects of pollution, while the aeroponic towers act as natural air cleaners. Adopting this creative blend shows a dedication to balancing human endeavours with the environment while simultaneously encouraging cleaner air. Optimizing aeroponic systems for balcony gardening and investigating their possible uses in urban settings will require further investigation and testing in the future. Additionally, promoting the adoption of green balcony practices and cultivating an environmental stewardship culture among residents may benefit from community involvement and educational initiatives.

Urban landscapes that integrate aeroponic towers and algae tanks provide a tangible route towards a sustainable future in which human health and the health of the planet coexist harmoniously while addressing the issues of urbanization and climate change.

Limitation of the Study

The pilot project's scope is restricted to testing an urban balcony facing a roadside that experiences tropical weather with an algae tank and an aeroponics plant palette. The study, which is conducted at the second-floor level, solely addresses the most frequent air pollutants, which include Particulate Matter (PM) 10, Particulate Matter (PM) 2.5, Sulphur dioxide, Nitrogen dioxide, Ammonia, Carbon monoxide, Carbon dioxide, formaldehyde, TVOCS, and benzene. Only April, the hottest month of the year, was used for the study.

Recognitions

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